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**Joshi**

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(54) **IMPLANTABLE MEDICAL DEVICE  
CHARGING APPARATUS HAVING BOTH  
PARALLEL AND SERIES RESONATORS**

(71) Applicant: **CYBERONICS, INC.**, Houston, TX  
(US)

(72) Inventor: **Himanshu Joshi**, Houston, TX (US)

(73) Assignee: **CYBERONICS, INC.**, Houston, TX  
(US)

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(56) **References Cited**

U.S. PATENT DOCUMENTS

4,209,783	A *	6/1980	Ohyama et al.	340/10.42
4,513,260	A *	4/1985	Ragan	333/165
4,561,443	A	12/1985	Hogrefe et al.	
4,665,896	A	5/1987	La Forge et al.	
5,154,172	A	10/1992	Terry, Jr. et al.	
5,222,494	A	6/1993	Baker, Jr.	
6,516,227	B1	2/2003	Meadows et al.	
6,972,543	B1	12/2005	Wells	
7,177,691	B2	2/2007	Meadows et al.	
7,729,760	B2	6/2010	Patel et al.	
7,751,891	B2	7/2010	Armstrong et al.	
7,769,466	B2	8/2010	Denker et al.	
9,041,484	B2 *	5/2015	Burgener et al.	333/101
2005/0075697	A1	4/2005	Olson et al.	

(Continued)

FOREIGN PATENT DOCUMENTS

GB 2297037 A 7/1996  
OTHER PUBLICATIONS

Yungtaek Jang et al., "A Contactless Electrical Energy Transmission  
System for Portable-Telephone Battery Chargers," IEEE Transac-  
tions on Industrial Electronics, vol. 50, No. 3, Jun. 2003, pp. 520-527.

(Continued)

Primary Examiner — M'baye Diao

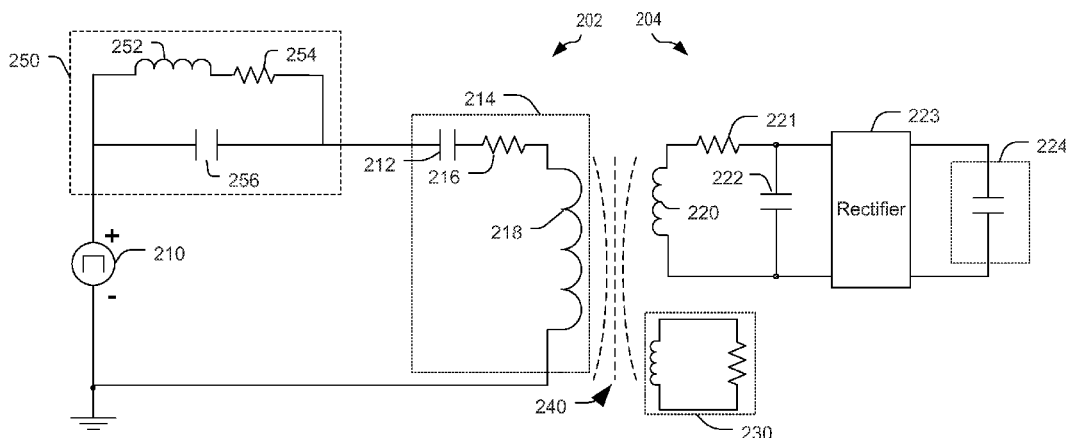
(74) Attorney, Agent, or Firm — Cyberonics, Inc.

(57)

**ABSTRACT**

An implantable medical device charging apparatus includes a  
charging circuit. The charging circuit includes a series reso-  
nator responsive to a signal applied to the charging circuit.  
During operation, the series resonator inductively couples to  
a secondary coil within an implantable medical device to  
transfer energy to the secondary coil. The charging circuit  
also includes a parallel resonator coupled to the series reso-  
nator. The parallel resonator filters a first component of the  
signal from propagating to the series resonator.

**20 Claims, 3 Drawing Sheets**



(56)

**References Cited**

## U.S. PATENT DOCUMENTS

2006/0247737	A1	11/2006	Olson et al.	
2007/0030096	A1 *	2/2007	Nishihara et al. ....	333/133
2009/0121806	A1 *	5/2009	Sasaki et al. ....	333/174
2009/0210035	A1	8/2009	Gelbart	
2009/0268647	A1 *	10/2009	Uejima .....	370/297
2010/0137948	A1	6/2010	Aghassian et al.	
2010/0171565	A1 *	7/2010	Okada .....	333/132
2010/0174348	A1 *	7/2010	Bulkes et al. ....	607/116
2010/0245186	A1 *	9/2010	Kojima .....	343/702
2011/0046699	A1	2/2011	Mazanec	
2012/0086281	A1 *	4/2012	Kanno .....	307/82
2012/0262108	A1	10/2012	Olson et al.	
2012/0277831	A1	11/2012	Joshi	
2014/0285016	A1 *	9/2014	Tetu et al. ....	307/31

## OTHER PUBLICATIONS

Sung-Noon Cho et al., "A Wireless Powered Fully Integrated SU-8-Based Implantable LC Transponder," Technical Paper, Microsyst Technol, Springer-Verlag 2010, Received Jul. 17, 2009, Accepted Feb. 16, 2010, Published Online, Mar. 9, 2010, 7 pages.

Gurhan Alper Kendir et al., "An Optimal Design Methodology for Inductive Power Link with Class-E Amplifier," IEEE Transactions on Circuits and Systems—I: Regular Papers, vol. 52, No. 5, May 2005, pp. 857-866.

International Application No. PCT/US2014/031664; PCT Search Report and Written Opinion dated Jul. 2, 2014, 7 pages.

\* cited by examiner

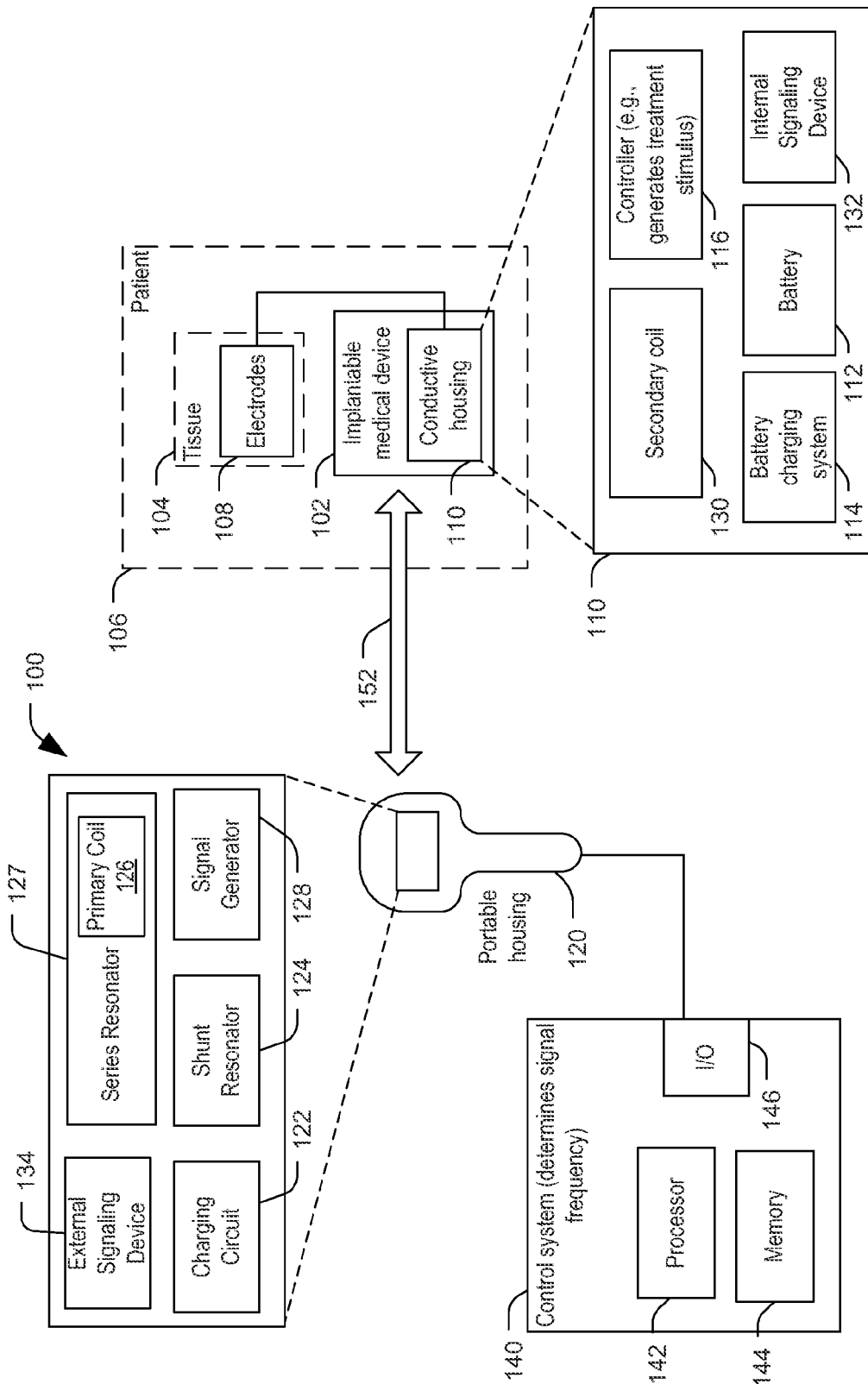


FIG. 1

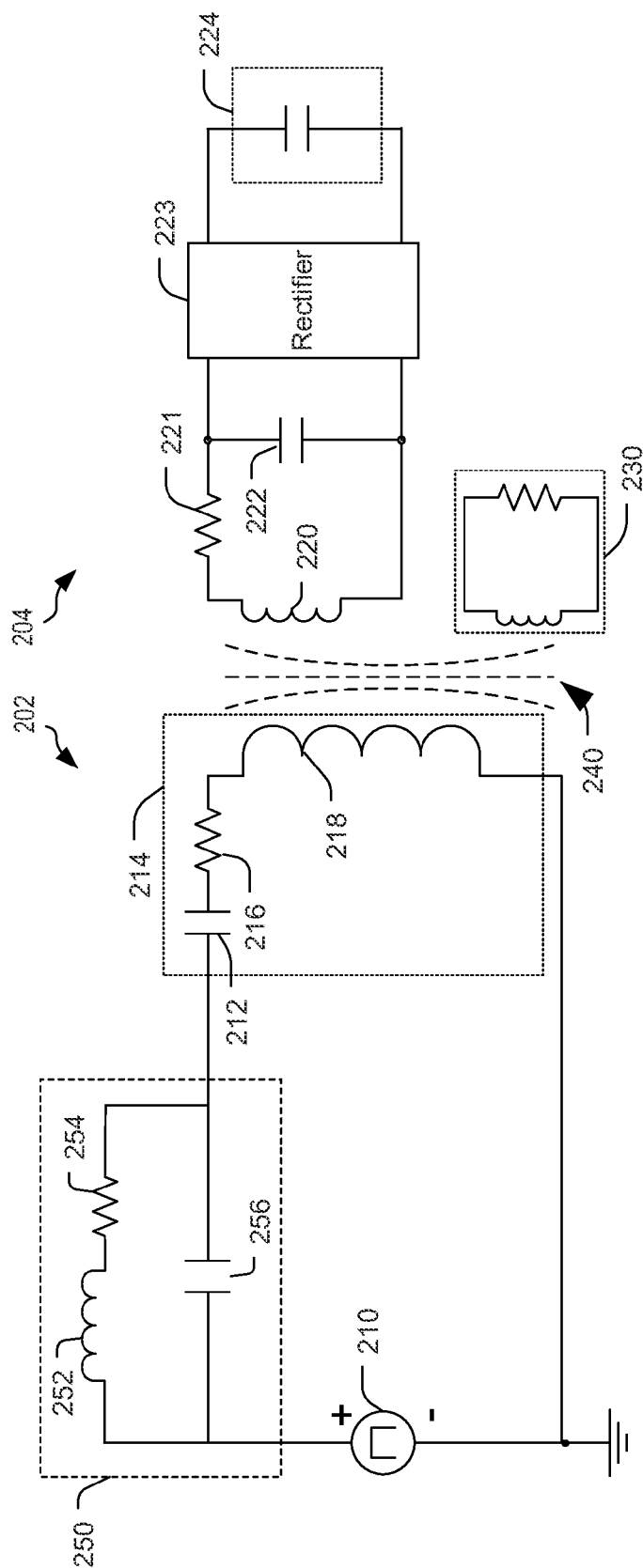


FIG. 2

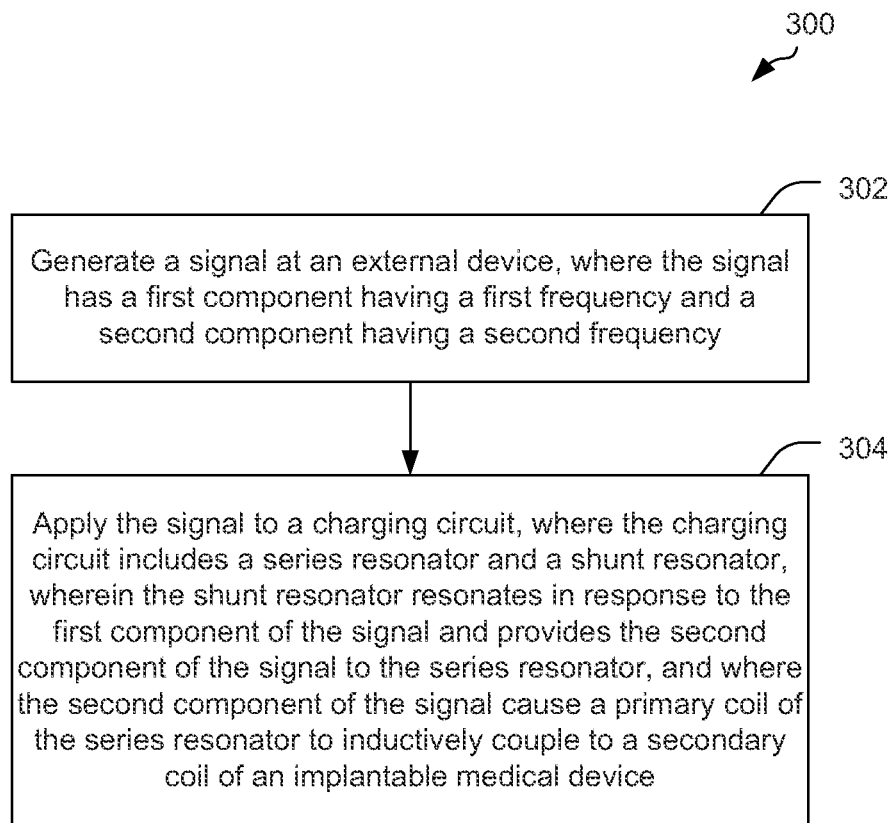


FIG. 3

1

# IMPLANTABLE MEDICAL DEVICE CHARGING APPARATUS HAVING BOTH PARALLEL AND SERIES RESONATORS

## FIELD OF THE DISCLOSURE

The present disclosure is generally related to implantable medical devices.

## BACKGROUND

Advances in technology have led to the development of miniature medical devices that can be implanted within a living organism, such as a human, to provide treatment or monitoring. Powering such implantable medical devices can be a concern. For example, some implantable medical devices use an onboard battery as a power source. However, since batteries store a finite amount of energy, an onboard battery may only be a temporary power source. Replacing batteries for implantable medical devices may be expensive and inconvenient. For example, depending on the specific nature of the implantable medical device, surgery may be needed to replace the device or to replace the battery.

Due to these and other concerns, some implantable medical devices use rechargeable batteries. However, recharging batteries that are located inside a device that is implanted in a patient presents other concerns. For example, when long charging times are required, patient compliance can be a problem. As another example, recharging batteries may cause an increase in radiation between the implantable medical device and an external system, such as a portable hand-held system used for recharging the batteries and used for communicating data to and from the implantable medical device. Increases in radiation may cause noise, which may cause errors when communicating data between the implantable medical device and external system.

## SUMMARY

A battery onboard an implantable medical device can be recharged using an inductively-coupled recharging system. For example, a device (e.g., an implantable medical device charging apparatus) that is external to a patient may include a charging circuit coupled to a series resonator that includes a primary coil. The implantable medical device may include a recharging circuit coupled to a secondary coil. The primary and secondary coils may be inductively coupled to enable transfer of energy from the primary coil to the secondary coil. The charging circuit may provide energy received by the secondary coil from the primary coil to a battery. Thus, the inductively-coupled recharging system enables the battery to be wirelessly recharged from a source external to the patient via the inductive coupling of the primary and secondary coils.

The implantable medical device may be programmable by an external signaling device. The external signaling device may be distinct (e.g., a separate device) or may be a component of, or integrated with, the device that is external to the patient. For example, the external signaling device (e.g., a first antenna or a first communication coil) may be used to communicate data to and from the implantable medical device via an internal signaling device (e.g., a second antenna or a second communication coil) of the implantable medical device. Data may be transferred between the external signaling device and the internal signaling device at a first frequency within a first frequency band. The series resonator used to recharge the implantable medical device may resonate at a second frequency within a second frequency band (e.g., a

2

frequency band at a lower frequency range than the first frequency band) to provide energy to the secondary coil.

When components of a charging signal provided to the charging circuit are within, or approximate to, the first frequency band, radiation at the primary coil may generate noise, which may interfere with data communication between the external signaling device and the internal signaling device. In addition, the primary coil may radiate at a frequency (e.g., the first frequency) used to communicate data, which may cause errors in data communication. Thus, it may be difficult for the device external to the patient to communicate data to the implantable medical device while charging the implantable medical device.

The circuitry used to generate the charging signal may use switching circuitry. Switching noise generated by the switching circuitry may couple on to wire leads and interfere with a stimulation signal or a sensing signal if the implantable medical device uses wire leads for electrical stimulation and/or sensing. Thus, stimulation dosing may be less precise and sensing may be less reliable.

To address such concerns, a parallel resonator may be implemented within the charging circuit to attenuate power that corresponds to high frequency components of the charging signal that would otherwise flow through the primary coil of the series resonator. For example, when the charging signal has a frequency component within the first frequency band (e.g., a high frequency harmonic component), the parallel resonator may resonate and behave in a manner similar to an open circuit. As a result, the high frequency harmonic component and/or noise may be substantially inhibited from propagating to the series resonator (and to the primary coil), thus attenuating an amount of noise and radiation at the primary coil during energy transfer. Communication between the external and internal signaling devices is improved by the reduced noise at the primary coil. Thus, in a particular embodiment, the parallel resonator may substantially inhibit (e.g., filter) high frequency components of the charging signal from flowing through the primary coil of the series resonator to reduce noise and radiation at the primary coil (and to improve communication, stimulation dosing, sensing, or a combination thereof).

In a particular embodiment, the parallel resonator may include a toroidal inductor that is coupled to a board of the charging circuit to reduce or eliminate radiation at the parallel resonator. The parallel resonator, designed to resonate at a frequency higher than the second frequency (e.g., the recharge frequency), may have an effective inductance at the second frequency. The effective inductance of the parallel resonator at the charging signal frequency may be added to the inductance of the series resonator when the charging signal has a frequency component within the second frequency band. As a result, the series resonator may use a smaller inductor (e.g., a smaller primary coil), thus improving the efficiency of the energy transfer substantially maintaining the total inductance of the charging circuit.

In a particular embodiment, an implantable medical device charging apparatus includes a charging circuit. The charging circuit includes a series resonator responsive to a signal applied to the charging circuit. During operation, the series resonator inductively couples to a secondary coil within an implantable medical device to transfer energy to the secondary coil. The signal includes a first component having a first frequency within a first frequency band and a second component having a second frequency within a second frequency band. The charging circuit also includes a parallel resonator

coupled to the series resonator. The parallel resonator filters the first component of the signal from propagating to the series resonator.

In a particular embodiment, a method of charging an implantable medical device includes generating a signal at an external device. The signal has a first component having a first frequency within a first frequency band and has a second component having a second frequency within a second frequency band. The method also includes applying the signal to a charging circuit. The charging circuit includes a series resonator and a parallel resonator. The parallel resonator resonates in response to the first component of the signal and provides the second component of the signal to the series resonator. The second component of the signal causes a primary coil of the series resonator to inductively couple to a secondary coil of an implantable medical device.

In a particular embodiment, a circuit for charging an implantable medical device includes a signal generator and a parallel resonator coupled to the signal generator. The signal generator generates a signal having a first component having a first frequency within a first frequency band and a second component having a second frequency within a second frequency band. The parallel resonator includes a parallel inductor and a parallel capacitor. The circuit also includes a series resonator coupled to the parallel resonator to inductively transfer energy to the secondary coil within the implantable medical device. The series resonator includes a capacitor and a primary coil. The parallel resonator inhibits the first component from propagating to the series resonator and provides the second component of the signal to the series resonator.

The features, functions, and advantages that have been described can be achieved independently in various embodiments or may be combined in yet other embodiments, further details of which are disclosed with reference to the following description and drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a particular embodiment of an implantable medical device and a charging system;

FIG. 2 is a simplified circuit diagram of a particular embodiment of an implantable medical device and a charging system; and

FIG. 3 is flow chart of a particular embodiment of a method of charging an implantable medical device.

#### DETAILED DESCRIPTION

FIG. 1 is a block diagram of a particular embodiment of an implantable medical device **102** and an external device **100**. In a particular embodiment, the external device **100** is an implantable medical device charging apparatus configured to charge the implantable medical device **102**. In another particular embodiment, the external device **100** is a device that is configured to communicate data with the implantable medical device **102** and that includes a component (e.g., an implantable medical device charging apparatus) to charge the implantable medical device **102**.

The implantable medical device **102** may be adapted to be surgically implanted in a patient **106** to provide therapy, to monitor one or more conditions, for another purpose, or any combination thereof. In a particular embodiment, the implantable medical device **102** may be coupled to one or more electrodes **108** and may be adapted to deliver electrical stimulus to tissue **104** of the patient **106** via the electrodes **108**. In a particular embodiment, the implantable medical device **102** is an implantable nerve stimulation device.

Examples of the implantable nerve stimulation device may include an implantable vagus nerve stimulation device, an implantable spinal cord stimulation device, etc. The electrodes **108** may be coupled to the implantable medical device **102** and may be positioned proximate to or coupled to a nerve, such as a cranial nerve (e.g., the trigeminal nerve, the hypoglossal nerve, the vagus nerve, a branch of the vagus nerve, glossopharyngeal nerve, or a combination thereof). The implantable medical device **102** may include a controller **116** that is configured to control generation of treatment stimulus provided to the electrodes **108** to provide an electrical stimulus to the tissue **104**. In another particular embodiment, the implantable medical device **102** is an implantable drug pump. In another particular embodiment, the implantable medical device **102** is an implantable sensor. Examples of an implantable sensor may include an electrocardiogram (ECG) sensor, an electroencephalogram (EEG) sensor, etc. Note that the term “patient” is used broadly to include any organism and is not intended to imply that the patient **106** is human; although the patient **106** is a human patient in one embodiment.

In a particular embodiment, the implantable medical device **102** may include a conductive housing **110**. One or more of a battery **112**, a battery charging system **114**, a secondary coil **130**, and other components of the implantable medical device **102** may be enclosed in the conductive housing **110**. The implantable medical device **102** may include a power supply, such as the battery **112**, that stores power to operate the implantable medical device **102**. The battery charging system **114** may be configured to receive power from the external device **100** to recharge the battery **112**. For example, the external device **100** may include a series resonator **127**. The series resonator **127** may include a primary coil **126** that is configured to inductively couple **152** to the secondary coil **130** within the implantable medical device **102**. The series resonator **127** may be responsive to a charging signal generated by a signal generator **128** and applied to a charging circuit **122** of the external device **100**. The signal generator **128** may include switching circuitry that may result in switching noise on the charging signal. The charging circuit **122** may include or be coupled to the primary coil **126**. The primary coil **126** may transfer energy to the secondary coil **130**. For example, in a particular embodiment, the primary coil **126** may function as a primary winding of a transformer and the secondary coil **130** may function as a secondary winding of a transformer. The battery charging system **114** may be coupled to the secondary coil **130** and may be configured to receive a current from the secondary coil **130** and to apply a charging voltage to the battery **112** responsive to the current.

The external device **100** may also include an external signaling device **134**. Alternatively or in addition, the external signaling device **134** may be a component of another external device (not shown). The implantable medical device **102** may include an internal signaling device **132**. The external device **100** may communicate data with the implantable medical device **102** over a first frequency band using the external and internal signaling devices **134**, **132**. The first frequency band may range from about 60 kilohertz (kHz) to about 100 kHz, and data may be communicated over a particular frequency (e.g., about 75 kHz) within the first frequency band. In a particular embodiment, the external signaling device **134** may include a first antenna and the internal signaling device **132** may include a second antenna. In some embodiments, the first frequency band may correspond to switching noise and may range from about 50 megahertz (MHz) to about 100 MHz, 100 MHz to 500 MHz, or any other high frequency

associated with switching noise. In a particular embodiment, the switching noise may have a frequency of approximately 85 MHz

The external device 100 may be configured to receive information from the implantable medical device 102 using the external and internal signaling devices 134, 132. For example, the external device 100 may receive information that is indicative of an electrical property associated with the implantable medical device 102 or an electrical property associated with a component of the implantable medical device 102, such as the battery 112, the battery charging system 114, another component of the implantable medical device 102, or any combination thereof. For example, the implantable medical device 102 may include a measurement system (not shown). The measurement system may measure the electrical property of the implantable medical device 102 or of the component of the implantable medical device 102, and the implantable medical device 102 may provide the information indicative of the electrical property to the external device 100 via wireless communication between the first and second signaling devices 134, 132. The electrical property measured by the measurement system may include a charge level of the battery 112, a voltage or current applied to the battery 112 by the battery charging system 114, another indication of an amount of power applied by the battery charging system 114 to the battery 112, another electrical property of a component of the implantable medical device 102, or any combination thereof.

The external device 100 may also include a parallel resonator 124 coupled to the series resonator 127. In a particular embodiment, the parallel resonator 124 and the series resonator 127 may be included in the charging circuit 122. The parallel resonator 124 may resonate at about the same frequency used to communicate data within the first frequency band. For example, the parallel resonator 124 may resonate in response to a 75 kHz signal. In another particular embodiment, the parallel resonator 124 may resonate at about the same frequency as the switching noise caused by the switching circuitry of the signal generator 128 within the first frequency band. For example, the parallel resonator 124 may resonate in response to an 85 MHz signal. In another particular embodiment, two or more parallel resonators may be used to resonate in response to two or more high frequency signals, respectively (e.g., 75 kHz and 85 MHz). The series resonator 127 may resonate at a lower frequency in a second frequency band. For example, the second frequency band may range from about 9 kHz to about 11 kHz, and the series resonator 127 may resonate in response to a 10 kHz signal.

The parallel resonator 124 is configured to reduce noise and radiation generated at the primary coil 126 of the series resonator 127 when the charging signal applied to the charging circuit 122 has a frequency component within the first frequency band (e.g., a high frequency component). For example, the signal generator 128 within, or coupled to, the charging circuit 122 may generate a charging signal having frequency components within the first frequency band (e.g., high frequency components) and frequency components within the second frequency band (e.g., low frequency components). As described with respect to FIG. 2, the parallel resonator 124 is configured to substantially inhibit (e.g., filter, block, or prevent) the high frequency components of the charging signal from propagating to the series resonator 127 and to provide the low frequency components of the charging signal to the series resonator 127. For example, the parallel resonator 124 may operate as an open circuit to filter the harmonics corresponding to the high frequency components of the charging signal from propagating to the series resonator

127. Filtering harmonics that correspond to the high frequency components of the charging signal may include reducing an amount of current, and thus an amount of power, in the portions of the charging signal that correspond to a frequency approximately within a 60 kHz to 100 kHz range, a 50 MHz to 100 MHz range, or a combination thereof.

Filtering the harmonics of the charging signal that correspond to the high frequency components within the first frequency band may also facilitate simultaneously charging the implantable medical device 102 using the charging signal and communicating data to a receiver within the implantable medical device 102 using a communication signal within the first frequency band. For example, filtering the high frequency components of the charging signal may reduce a likelihood of signal interference with the communication signal, which may cause errors during data communication.

The parallel resonator 124 is further configured to contribute to the inductance of the series resonator 127 for the low frequency components of the charging signal generated by the signal generator 128. For example, in a low frequency range, the parallel resonator 124 may have an effective inductance and may provide the low frequency components of the charging signal to the series resonator 127. The effective inductance of the parallel resonator 124 may be added to the inductance of the series resonator 127 (e.g., the inductance of the primary coil 126) increasing an effective coil size of the primary coil 126, which may enable use of a smaller primary coil 126 without affecting the total inductance. The parallel resonator 124 may include a toroidal inductor coupled to a board of the charging circuit 122 to minimize or reduce radiation at the parallel resonator 124.

The external device 100 may include a control system 140. The control system 140 may control application of charging signals generated by the signal generator 128. The control system 140 may include one or more processors, such as a processor 142, and memory accessible to the processor 142, such as a memory 144. The memory 144 may include tangible, non-transitory, computer-readable media (e.g., one or more computer memory devices). The processor 142 may be implemented using a single-chip processor or using multiple processors. The memory 144 may include various memory devices, such as registers, cache, volatile memory, and non-volatile memory. For example, the memory 144 can include cache that is accessible by the processor 142 to rapidly retrieve and store data. The memory 144 can include any data storage device that can store data which can thereafter be read by the control system 140 or by another computing system. Examples of computer-readable media that the memory 144 may use include, but are not limited to: magnetic media such as hard disks, floppy disks, and magnetic tape; optical media such as CD-ROM disks; magneto-optical media; and specially configured hardware devices such as application-specific integrated circuits (ASICs), programmable logic devices (PLDs), and ROM and RAM devices.

The memory 144 may store instructions that are executable by the processor 142 to implement various functions of the control system 140. To illustrate, the instructions may be executable by the processor 142 to control charging signals generated by the signal generator 128, to process information received from the implantable medical device 102, and so forth. For example, the instructions may be executable by the processor 142 to control the characteristics (e.g., frequency, amplitude, duty cycle, polarity, pulse width, pulse period, signal duration, etc.) of the charging signal generated by the signal generator 128 within, or coupled to, the charging circuit 122.

Additionally or in the alternative, the control system **140** may include dedicated hardware implementations, such as application specific integrated circuits, programmable logic arrays and other hardware devices, to implement one or more functions of the control system **140**. Accordingly, the present disclosure encompasses software, firmware, and hardware implementations.

The control system **140** may also include an input/output (I/O) interface **146**. The I/O interface **146** may enable the control system **140** to send and receive information and signals to other components of the external device **100**. For example, the charging circuit **122** and the primary coil **126** (as well as one or more other components) may be housed within a portable housing **120**, such as a handheld wand or other device. The control system **140** may send control information and signals to the portable housing **120** via the I/O interface **146** and may receive information from the portable housing **120** via the I/O interface **146**.

During operation, the signal generator **128** may generate a charging signal having high frequency components within the first frequency band and low frequency components within the second frequency band. The parallel resonator **124** may attenuate power corresponding to the high frequency components and provide the low frequency components of the charging signal to the series resonator **127**. For example, the parallel resonator **124** may reduce or eliminate current corresponding to high frequency components of the charging signal from propagating to the series resonator **127**. As described with respect to FIG. 2, the parallel resonator **124** may resonate in response to the high frequency components of the charging signal, causing the parallel resonator **124** to function as an open circuit, thus reducing or eliminating current corresponding to the high frequency components of the charging signal from propagating to the series resonator **127**. The portions of the charging signal that have low frequency components may propagate through an inductor (not shown) of the parallel resonator **124** and may be provided to the series resonator **127**, causing the series resonator **127** to resonate. The primary coil **127** inductively couples **152** to the secondary coil **130** of the implantable medical device **102** using the portions of the charging signal with the low frequency components to charge the implantable medical device **102**. Noise in a high frequency range (e.g., a frequency range used for data communication or higher) may be reduced during inductive coupling **152** by inhibiting (e.g., filtering) high frequency components of the charging signal.

The external device **100** may charge the implantable medical device **102** using low frequency components of the charging signal within the second frequency band while simultaneously communicating data to a receiver within the implantable medical device **102** using a high frequency communication signal (e.g., a 75 kHz signal) within the first frequency band. The parallel resonator **127** may substantially inhibit (e.g., filter, block, or prevent) high frequency components of the charging signal from propagating to the series resonator **127** and may provide low frequency components of the charging signal to the series resonator **127** to charge the battery **112** of the implantable medical device **102**. Meanwhile, the external device **100** may communicate with the implantable medical device **102** using a frequency that corresponds to the high frequency components that are filtered by the parallel resonator **127**. Charging the implantable medical device **102** using the low frequency components of the charging signal while the parallel resonator **124** filters the high frequency components of the charging signal may facilitate simultaneous charging of the implantable medical device **102** and data communication with the implantable medical

device **102**. For example, filtering the high frequency components of the charging signal may reduce a likelihood of signal interference, which may cause errors during data communication.

In some embodiments, the parallel resonator **124** may be provided to substantially inhibit (e.g., filter, block, or prevent) high frequency components of the charging signal (e.g., 85 MHz) caused by switching noise from propagating to the series resonator **127** and may provide low frequency components of the charging signal to the series resonator **127** to charge the battery **112** of the implantable medical device **102**.

FIG. 2 is a simplified circuit diagram of a particular embodiment of an implantable medical device and a charging circuit. In particular, the simplified circuit diagram illustrates an external charging circuit **202** that is inductively coupled **240** to an internal system, such as an implantable medical device **204**. Power may be transferred from the external charging circuit **202** to the implantable medical device **204** to recharge a power source of the implantable medical device **204** via inductive coupling **240**. In a particular embodiment, the external charging circuit **202** may include, be included within, or correspond to the external device **100** of FIG. 1. For example, in a particular embodiment, the external charging circuit **202** may include the charging circuit **122** of FIG. 1 and may operate in a substantially similar manner. Further, the implantable medical device **204** may correspond to the implantable medical device **102** of FIG. 1 and may operate in a substantially similar manner.

In a particular embodiment, the implantable medical device **204** includes a secondary coil **220**, a secondary resistor **221** (e.g., may correspond to resistive losses of the secondary coil **220**), and a secondary capacitor **222**. The secondary coil **220**, the secondary resistor **221**, and the secondary capacitor **222** may be included in a resistive (R), inductive (L), and capacitive (C) circuit (also referred to as an "RLC circuit"). The RLC circuit comprising the secondary coil **220**, the secondary resistor **221**, and the secondary capacitor **222** may resonate in response to a charging signal within the second frequency band (e.g., from about 9 kHz to 11 kHz).

The implantable medical device **204** also includes a rectifier **223** and a rechargeable power supply **224** (such as a battery, a capacitor, or another energy storage device). For example, the rechargeable power supply **222** may include or be included within the battery **112** of the FIG. 1. Current generated at the RLC circuit of the implantable medical device **204** may be applied to the rectifier **223** and then to the rechargeable power supply **224** as a rectified voltage to charge the rechargeable power supply **224**. The implantable medical device **204** may include a conductive housing **230**. The conductive housing **230** is illustrated separately from the implantable medical device **204** to illustrate the inductive coupling **240** of the external charging circuit **202** with the conductive housing **230**.

The external charging circuit **202** may include a signal generator **210**, a parallel resonator **250**, and a series resonator **214**. In a particular embodiment, the signal generator **210** may correspond to the signal generator **128** of FIG. 1 and may operate in a substantially similar manner, the parallel resonator **250** may correspond to the parallel resonator **124** of FIG. 1 and may operate in a substantially similar manner, and the series resonator **214** may correspond to the series resonator **127** of FIG. 1 and may operate in a substantially similar manner. The signal generator **210** may generate a charging signal having high frequency components within the first frequency band (e.g., about 60 kHz to about 100 kHz, and/or

about 50 MHz to 100 MHz) and having low frequency components within the second frequency band (e.g., about 9 kHz to about 11 kHz).

The series resonator **214** may include a capacitor **212**, a resistor **216** (e.g., may correspond to resistive losses of the primary coil **218**), and a primary coil **218** coupled in series. For example, a second terminal of the capacitor **212** may be coupled to a first terminal of the resistor **214**, and a second terminal of the resistor **214** may be coupled to a first terminal of the primary coil **218**. A second terminal of the signal generator **210** may be coupled to a second terminal of the primary coil **218**. The arrangement of the components of the series resonator **214** may change in other embodiments.

The primary coil **218** may correspond to the primary coil **126** of FIG. 1 and may operate in a substantially similar manner. The primary coil **218** may include a radial inductor configured to radiate outward and generate a magnetic field or an electromagnetic field to facilitate inductive coupling **240** (and thus energy transfer) with the secondary coil **220**. The series resonator **214** may exhibit capacitance via the capacitor **212**, resistance via the resistor **216**, and inductance via the primary coil **218**. Thus, the series resonator **214** is also an RLC circuit. In a particular embodiment, other circuit elements of the external charging circuit **202** may contribute to the resistance of the series resonator **214**. In a particular embodiment, the resonant frequency of the series resonator **214** may be about 10 kHz (e.g., within the second frequency band). The resonant frequency is an efficient frequency at which to operate the series resonator **214** since losses due to impedance and capacitance are reduced. Another characteristic of the resonant frequency of an RLC circuit is that, at the resonant frequency, current and voltage of a signal applied to the RLC circuit are in phase.

The parallel resonator **250** may include a parallel resistor **254** (e.g., may correspond to resistive losses of the parallel inductor **252**) coupled in series with a parallel inductor **252**. The parallel resonator **250** may also include a parallel capacitor **256** coupled in parallel with the parallel resistor **254** and the parallel inductor **252**. The arrangement or order of the components of the parallel resonator **250** may be different in other embodiments. Thus, the parallel resonator **250** is also an RLC circuit. In a particular embodiment, the resonant frequency of the parallel resonator **250** may be within the first frequency band (e.g., about 75 kHz, and/or about 85 MHz). The parallel inductor **252** may be a torodial inductor that is coupled to a board of the external charging circuit **202**. For example, the parallel inductor **252** may radiate inward as to reduce or eliminate radiation caused by the parallel resonator **250**.

The parallel resonator **250** is configured to reduce noise and radiation generated in the first frequency band at the primary coil **218** of the series resonator **214** that would otherwise be caused by the charging signal. For example, the parallel resonator **250** may substantially inhibit (e.g., filter, block or prevent) harmonics corresponding to the high frequency components (e.g., frequency components within the first frequency band) of the charging signal. In a particular embodiment, the parallel resonator **250** may resonate in response to the high frequency components of the charging signal. For example, the parallel resonator **250** may resonate in response to frequency components within the first frequency band (e.g., frequency components ranging from about 60 kHz to about 100 kHz, and/or 50 MHz to 100 MHz). When the parallel resonator **250** resonates, the parallel resonator **250** may operate in a manner similar to an open circuit and substantially inhibit or filter the high frequency components from being provided to the series resonator **214**. Inhibiting

(e.g., filtering) the high frequency components of the charging signal from being provided to the series resonator **214** may reduce radiation of signals in the first frequency band at the primary coil **218**.

The parallel resonator **250** may be designed to filter particular harmonics of the charging signal. For example, the parallel resonator **250** may resonate, and thus filter particular frequency components of the charging signal, based on the capacitance of the parallel capacitor **256** and the inductance of the parallel inductor **252**. In a particular embodiment, multiple parallel resonators may be used in series to notch out multiple frequency components of concern. For example, a second parallel resonator (not shown) with a capacitance and inductance designed to filter out frequency components within a third frequency band (e.g., from about 20 kHz to 50 kHz, or 50 MHz to 100 MHz) may be added to the external charging circuit **202**.

The parallel resonator **250** is also configured to contribute to the inductance of the series resonator **214**. For example, the parallel resonator **250** may function in a manner similar to an inductor in response to the low frequency components of the charging signal and may provide the low frequency components of the charging signal to the series resonator **214**. The inductance of the parallel resonator **250** may contribute to the effective inductance of the series resonator **214**. The parallel inductor **252** may be a torodial inductor coupled to a circuit board of the external charging circuit **202** to reduce or eliminate radiation at the parallel resonator **250**. Thus, a smaller primary coil **218** may be used in the series resonator **214** without reducing an effective inductance of the external charging circuit **202**.

During operation, the signal generator **210** may generate a charging signal having high frequency components and low frequency components and may provide the charging signal to the parallel resonator **250**. The parallel resonator **250** may filter the high frequency components of the charging signal from propagating to the series resonator **214**. The parallel resonator **250** may provide the low frequency components of the charging signal to the series resonator **214**. For example, in response to the high frequency components of the charging signal, the parallel resonator **250** may function as an open circuit and substantially inhibit (e.g., filter, block, or prevent) portions of the charging signal that correspond to the high frequency components from propagating to the series resonator **214**. In response to the low frequency components of the charging signal, the parallel resonator **250** may function as an inductor and provide the low frequency components of the charging signal to the series resonator **202**. The low frequency components of the charging signal provided to the series resonator **214** may cause the series resonator **214** to resonate, enabling the primary coil **218** to inductively couple **240** to the secondary coil **220** of the implantable medical device **102** to provide a current to the secondary coil **220**.

A voltage based on the current at the secondary coil **220** is provided to the rechargeable power supply **224** to recharge the implantable medical device **204**. Radiation and noise in a high frequency range may be reduced at the primary coil **126** during inductive coupling **240** in response to parallel resonator **240** filtering the high frequency components of the charging signal from the series resonator **214** and providing the low frequency components of the charging signal to the series resonator **214**.

The parallel resonator **250** may also facilitate simultaneous data communication with the implantable medical device **204** using a first frequency (e.g., 75 kHz) and recharging of the implantable medical device **204** using a second frequency (e.g., 10 kHz). For example, charging the implantable medi-

11

cal device **204** using the second frequency within the second frequency band while the parallel resonator **250** filters the first frequency within the first frequency band may reduce a likelihood of signal interference, which may cause communication errors.

FIG. 3 is a flow chart of a particular method **300** of charging an implantable medical device. For example, the method **300** may be performed by an external charging system and the components thereof, such as the charging circuit **122** of FIG. 1, the parallel resonator **124** of FIG. 1, the signal generator **128** of FIG. 1, the series resonator **127** of FIG. 1, the external charging system **202** of FIG. 2, the signal generator **210** of FIG. 2, the parallel resonator **250** of FIG. 2, the series resonator **214** of FIG. 2, or any combination thereof. The method **300** may be performed during charging of an implantable medical device, such as the implantable medical device **102** of FIG. 1 or the implantable medical device **204** of FIG. 2. In a particular embodiment, the implantable medical device may include a nerve stimulation device. The nerve stimulation device may include a secondary coil, a battery and a battery charging circuit within a conductive housing. The secondary coil may be responsive to a charging signal applied to the primary coil of an external charging circuit to provide energy to charge the battery. In this particular embodiment, the battery may be charged during data communication with the implantable medical device.

The method **300** may include generating a signal at an external device, at **302**. For example, in FIG. 1, the signal generator **128** may generate the charging signal. The charging signal may have a first component (e.g., a high frequency component) having a first frequency within the first frequency band (e.g., about 60 kHz to about 100 kHz, and/or 50 MHz to 100 MHz) caused by the charging signal harmonics and/or switching noise from the signal generator. The charging signal may also have a second component (e.g., a low frequency component) having a second frequency within the second frequency band (e.g., about 9 kHz to 11 kHz). As another example, in FIG. 2, the signal generator **210** may generate the charging signal.

The signal may be applied to a charging circuit, at **304**. For example, in FIG. 1, the signal generator **128** may apply the charging signal to the parallel resonator **124** of the charging circuit **122**. The parallel resonator **124** may resonate in response to the first component of the charging signal. The parallel resonator **124** may function as an open circuit and substantially inhibit (e.g., filter, block, or prevent) the first component of the charging signal from propagating to the series resonator **127**. The parallel resonator **124** may provide the second component of the charging signal to the series resonator **127**. The second component of the charging signal may cause the primary coil **126** of the series resonator **127** to inductively couple **152** to the secondary coil **130** of the implantable medical device **102**.

As another example, in FIG. 2, the signal generator **210** may apply the charging signal to the parallel resonator **250** of the external charging circuit **202**. The parallel resonator **250** may resonate in response to the first component of the charging signal. The parallel resonator **250** may function as an open circuit and substantially inhibit (e.g., filter, block, or prevent) the first component of the charging signal from propagating to the series resonator **214**. In response to the second component of the charging signal, the parallel resonator **250** may function as an inductor and provide the second component of the charging signal to the series resonator **214**. The second component of the charging signal may cause the primary coil **218** of the series resonator **214** to inductively couple **240** to the secondary coil **220** of the implantable medical device **204**.

12

In a particular embodiment, the series resonator may resonate in response to the second component of the signal. For example, in FIG. 1, the series resonator **127** may resonate in response to the low frequency component of the charging signal. As another example, in FIG. 2, the series resonator **214** may resonate in response to the low frequency component of the charging signal.

In a particular embodiment, energy may be inductively transferred to the secondary coil within the implantable medical device via the primary coil of the charging circuit to recharge the implantable medical device. For example, in FIG. 1, the primary coil **126** of the series resonator **127** may inductively couple **152** to the secondary coil **130** of the implantable medical device **102** in response to the second component of the charging signal. A current may be generated at the secondary coil **130** based on the inductive coupling **152**, and the battery charging system **114** may apply a charging voltage to the battery **112** in response to the current. As another example, in FIG. 2, the primary coil **218** may inductively couple **240** to the secondary coil **220** of the implantable medical device **204** in response to the second component of the charging signal. The secondary coil **220** may generate a current based on the inductive coupling **152**, and a charging voltage may be applied to the rectifier **223** and then to the rechargeable power supply **224** in response to the current.

The method **300** may enable an external device to simultaneously communicate data to and from an implantable medical device at a first frequency (e.g., a high frequency) and to charge the implantable medical device at a second frequency (e.g., a low frequency). For example, the parallel resonator **124** may substantially inhibit (e.g., filter, block, or prevent) high frequency components of the charging signal from the series resonator **127**. Filtering the high frequency components may reduce radiation and noise at a frequency of the high frequency components during inductive coupling **152**, and may also permit inductive recharging using the second frequency corresponding to the low frequency components of the charging signal (as opposed to inductive recharging using both the high frequency components and the low frequency components of the charging signal). Communicating data over a first frequency and charging over a second frequency may reduce interference and errors during data communication.

The illustrations of the embodiments described herein are intended to provide a general understanding of the structure of the various embodiments. The illustrations are not intended to serve as a complete description of all of the elements and features of apparatus and systems that utilize the structures or methods described herein. Many other embodiments may be apparent to those of skill in the art upon reviewing the disclosure. Other embodiments may be utilized and derived from the disclosure, such that structural and logical substitutions and changes may be made without departing from the scope of the disclosure. For example, method steps may be performed in a different order than is shown in the figures or one or more method steps may be omitted. Accordingly, the disclosure and the figures are to be regarded as illustrative rather than restrictive.

Moreover, although specific embodiments have been illustrated and described herein, it should be appreciated that any subsequent arrangement designed to achieve the same or similar results may be substituted for the specific embodiments shown. This disclosure is intended to cover any and all subsequent adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, will be apparent to those of skill in the art upon reviewing the description.

13

The Abstract of the Disclosure is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, various features may be grouped together or described in a single embodiment for the purpose of streamlining the disclosure. This disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, the claimed subject matter may be directed to less than all of the features of any of the disclosed embodiments.

What is claimed is:

1. An implantable medical device charging apparatus comprising:

a charging circuit, wherein the charging circuit includes: a series resonator responsive to a signal applied to the charging circuit, the series resonator configured to inductively couple to a secondary coil within an implantable medical device to transfer energy to the secondary coil, the signal having a first component having a first frequency within a first frequency band and a second component having a second frequency within a second frequency band; and a first parallel resonator coupled to the series resonator, the first parallel resonator configured to filter the first component of the signal from propagating to the series resonator.

2. The implantable medical device charging apparatus of claim 1, wherein the series resonator includes a primary coil and the first parallel resonator includes a parallel inductor.

3. The implantable medical device charging apparatus of claim 2, wherein the primary coil is a radial inductor and wherein the parallel inductor is a torodial inductor.

4. The implantable medical device charging apparatus of claim 1, wherein the charging circuit further comprises:

a signal generator configured to generate the signal, wherein the first component is switching noise caused by the signal generator.

5. The implantable medical device charging apparatus of claim 4, wherein the first frequency band ranges from 50 megahertz (MHz) to 100 MHz.

6. The implantable medical device charging apparatus of claim 1, wherein the first parallel resonator is configured to provide the second component of the signal to the series resonator, wherein the second frequency band has a lower frequency range than the first frequency band, wherein the series resonator resonates in response to receiving the second component of the signal.

7. The implantable medical device charging apparatus of claim 1, wherein the charging circuit further comprises:

a signal generator configured to generate the signal, wherein the first component is a harmonic of the signal.

8. The implantable medical device charging apparatus of claim 7, wherein the first frequency band ranges from 60 kilohertz (kHz) to 100 kHz.

9. The implantable medical device charging apparatus of claim 1, wherein the second frequency band ranges from 9 kilohertz (kHz) to 11 kHz.

10. The implantable medical device charging apparatus of claim 1, wherein the charging circuit further comprises:

a second parallel resonator coupled in series with the first parallel resonator and the series resonator, the second parallel resonator configured to filter a third component having a third frequency within a third frequency band of the signal from propagating to the series resonator.

11. The implantable medical device charging apparatus of claim 10, wherein the first frequency band ranges from 60

14

kilohertz (kHz) to 100 kHz and the third frequency band ranges from 50 megahertz (MHz) to 100 MHz.

12. A method comprising:

generating a signal at an implantable medical device charging apparatus, wherein the signal has a first component having a first frequency within a first frequency band and has a second component having a second frequency within a second frequency band;

applying the signal to a charging circuit, wherein the charging circuit includes a series resonator and a first parallel resonator, wherein the first parallel resonator inhibits the first component of the signal from propagating to the series resonator and provides the second component of the signal to the series resonator, and wherein the second component of the signal causes a primary coil of the series resonator to inductively couple to a secondary coil of an implantable medical device.

13. The method of claim 12, wherein the series resonator resonates in response to the second component of the signal.

14. The method of claim 12, wherein the first parallel resonator resonates in response to the first component of the signal to inhibit the first component of the signal from propagating to the series resonator.

15. The method of claim 12, wherein the first frequency band ranges from 60 kilohertz (kHz) to 100 kHz or from 50 megahertz (MHz) to 100 MHz, and wherein the second frequency band ranges from 9 kHz to 11 kHz.

16. The method of claim 12, further comprising communicating data to a receiver within the implantable medical device, wherein the data is communicated over the first frequency band and wherein the implantable medical device charging apparatus charges the implantable medical device over the second frequency band.

17. The method of claim 12, wherein the signal has a third component having a third frequency within a third frequency band, wherein the charging circuit includes a second parallel resonator, wherein the second parallel resonator inhibits the third component of the signal from propagating to the series resonator and provides the second component of the signal to the series resonator.

18. The method of claim 17, wherein the first frequency band ranges from 60 kilohertz (kHz) to 100 kHz and the third frequency band ranges from 50 megahertz (MHz) to 100 MHz.

19. A circuit comprising:

a signal generator configured to generate a signal, the signal having a first component having a first frequency within a first frequency band and a second component having a second frequency within a second frequency band;

a parallel resonator coupled to the signal generator, wherein the parallel resonator includes a parallel inductor and a parallel capacitor;

a series resonator coupled to the parallel resonator, the series resonator configured to inductively transfer energy to a secondary coil within an implantable medical device, wherein the series resonator includes a capacitor and a primary coil, wherein the parallel resonator is configured to inhibit the first component from propagating to the series resonator and to provide the second component of the signal to the series resonator.

20. The circuit of claim 19, wherein the first component is a harmonic of the signal or switching noise caused by the signal generator.